

Claims

[c1] What is claimed is:

1. A lumped-element low-pass filter formed in a multi-layered substrate comprising:
 - a first inductor;
 - a second inductor electrically connected to the first inductor in series at one end, wherein the first and second inductors are spiral in shape and the orientations of the first inductor and the second inductor are of opposite sense such that a mutual inductance between the first inductor and the second inductor is negative and equals a first value;
 - a first capacitor shunt-connected to the first inductor;
 - a second capacitor shunt-connected to the second inductor; and
 - a third capacitor having a first end electrically connected to ground and a second end electrically connected to the end of the second inductor at which the second inductor is connected to the first inductor.

[c2] 2. The lumped-element low-pass filter of claim 1 wherein the first inductor is formed on a fourth layer of the multi-layered substrate, the second inductor is

formed on a third layer of the multi-layered substrate and is electrically connected to the first inductor in series through a first via penetrating the substrate, the first capacitor comprises two plates formed on a fifth layer and a sixth layer of the multi-layered substrate, in which the plate formed on the fifth layer is connected to the first inductor through a second via penetrating the substrate and the plate formed on the sixth layer is connected to the first via, the second capacitor comprises two plates formed on a first layer and a second layer of the multi-layered substrate, in which the plate formed on the second layer is connected to the second inductor through a third via penetrating the substrate and the plate formed on the first layer is connected to the first via, and the third capacitor is formed between the first layer and a ground layer of the multi-layered substrate, in which the first layer is next to the ground layer.

- [c3] 3. The lumped-element low-pass filter of claim 2 wherein the sixth layer is next to the ground layer so that a fourth capacitor is formed between the sixth layer and the ground layer and is shunt-connected with the third capacitor.
- [c4] 4. The lumped-element low-pass filter of claim 2 wherein the first and second capacitors sandwich the first and second inductors.

[c5] 5. The lumped-element low-pass filter of claim 1 wherein the first inductor is formed on a fourth layer of the multi-layered substrate, the second inductor is formed on a third layer of the multi-layered substrate and is electrically connected to the first inductor in series through a first via penetrating the substrate, the first capacitor comprises two plates formed on a fifth layer and a sixth layer of the multi-layered substrate, in which the plate formed on the sixth layer is connected to the first inductor through a second via penetrating the substrate and the plate formed on the fifth layer is connected to the first via, the second capacitor comprises two plates formed on a first layer and a second layer of the multi-layered substrate, in which the plate formed on the second layer is connected to the second inductor through a third via penetrating the substrate and the plate formed on the first layer is connected to the first via, and the third capacitor is formed between the first layer and a ground layer of the multi-layered substrate, in which the first layer is next to the ground layer.

[c6] 6. The lumped-element low-pass filter of claim 5 wherein the first and second capacitors sandwich the first and second inductors.

[c7] 7. The lumped-element low-pass filter of claim 1

wherein the first inductor is formed on a third layer of the multi-layered substrate, the second inductor is also formed on the third layer and is electrically connected to the first inductor in series at an end, the first capacitor comprises two plates formed on a fourth layer and a fifth layer of the multi-layered substrate, in which the plate formed on the fifth layer is connected to the end of the second inductor at which the second inductor is connected to the first inductor through a first via penetrating the substrate and the plate formed on the fourth layer is connected to the first inductor through a second via penetrating the substrate, the second capacitor comprises two plates formed on a first layer and a second layer of the multi-layered substrate, in which the plate formed on the second layer is connected to the second inductor through a third via penetrating the substrate and the plate formed on the first layer is connected to the first via, and the third capacitor is formed between the first layer and a ground layer of the multi-layered substrate, in which the first layer is next to the ground layer.

[c8] 8. The lumped-element low-pass filter of claim 7 wherein the first and second capacitors sandwich the first and second inductors.

- [c9] 9. The lumped-element low-pass filter of claim 1 wherein the third capacitor is two shunt-connected capacitors, each of which is formed on at least one layer of the multi-layered substrate.
- [c10] 10. The lumped-element low-pass filter of claim 1 wherein the multi-layered substrate is a low temperature co-fired ceramic (LTCC) substrate.
- [c11] 11. The lumped-element low-pass filter of claim 1 wherein spirals of the first and second inductors are rectangular, circular, or octagonal in shape.
- [c12] 12. The lumped-element low-pass filter of claim 1 wherein the first value is according to a predetermined characteristic of frequency response and values of the first inductor, the second inductor, the first capacitor, the second capacitor, and the third capacitor.
- [c13] 13. The lumped-element low-pass filter of claim 1 wherein the first value is according to shapes of and a relative distance between the first inductor and the second inductor so that the mutual inductance equals the first value.
- [c14] 14. The lumped-element low-pass filter of claim 1 wherein at least one inductor is formed on a plurality of layers of the multi-layered substrate.

[c15] 15. The lumped-element low-pass filter of claim 1 wherein at least one capacitor comprises a plurality of plates formed on a plurality of layers of the multi-layered substrate.